STATEMENT OF WORK FOR
COTS WATER MIST SYSTEM CERTIFICATION

1. **INTRODUCTION.** The U.S. Navy is interested in investigating the suitability of employing Commercial-of-the-Self (COTS) high-pressure water mist technology for machinery space fire protection. The National Fire Protection Associations standard on Water Mist Protection Systems (NFPA 750) classifies high-pressure as 500 psi (43.5 bar) or higher based on pressure exerted on the distributed piping. Final fire tests will be conducted at the Navy's full-scale RDT&E fire test ship, ex-USS *Shadwell* located in Mobile, AL, USA in accordance with reference (1).

2. **SCOPE.** The contractor shall review the firefighting performance requirements noted in reference (1) and supply information/documents that note that the COTS water mist fire extinguishing system they propose could meet the Navy's fire test standard for machinery space fire protection. The contractor shall provide a Commercial Off the Shelf (COTS) High-Pressure Water Mist System that produces water particles under 100 micrometers in a concentration that exceeds 0.4 liters per minute per cubic meter(0.003 gallons per minute per cubic foot).

3. **DOCUMENTATION.** The contractor shall submit all applicable documentation detailing the technical description of their water mist system hardware and any International Maritime Organization (IMO) marine approvals gained or approvals applied for.

Fire Performance Requirements for Water Mist Systems Installed in Machinery Spaces on U.S. Navy Ships

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FIRE PERFORMANCE REQUIREMENTS FOR WATER MIST SYSTEMS INSTALLED IN MACHINERY SPACES ON U.S. NAVY SHIPS

1.0 INTRODUCTION

Water mist fire suppression systems have been and continue to be considered for protecting the spectrum of fire hazards on U.S. Navy ships. Two different types of water mist systems are currently being developed/assessed by the U.S. Navy. These include the high pressure (70 bar (1,000 psi)) water mist system (HPWMS) currently being installed on the LPD 17 and LHD 8 [1] (also expanded during DC-ARM [2]); and, the intermediate pressure (17.5 bar (250 psi)) water mist system (IPWMS) currently being developed for the DD(X) [3]. Both systems have demonstrated significant increases in Damage Control (DC) capabilities and the potential for reductions in DC manning. Both are also being considered for DDG 51 backfit (and forward fit) applications [4].

The performance requirements for water mist systems installed on U.S. Navy ships have never been explicitly defined. As a result, the design parameters and capabilities of the HPWMS and the IPWMS are significantly different. The HPWMS parameters and capabilities were quantified during a multi-year research program conducted by the Navy. The IPWMS designs were initially developed based on commercial standards and manufacturers' recommendations and requirements developed by the program office and design yard. The IPWMS was assessed in DD(X) EDM demonstrations, which do not include a full parametric study to quantify performance. The commercial standards used to approve these systems are comprised of relatively easy fires to extinguish when compared to the LPD 17 test fires. This has resulted in the approval of commercially available systems with minimal discharge rates and very wide nozzle spacings. The reduced discharge rate of commercially approved systems makes them much more attractive for shipboard applications, due to both cost and ship impact (space and weight). However, the lower discharge rate reduces the capabilities of the system to potentially unacceptable levels when applied to a naval combatant.

The objective of this task was to define the fire performance requirements of water mist systems used for protecting machinery spaces on U.S. Navy ships. More specifically, this standard defines the minimum fire performance requirements of the system for protecting against the range/spectrum of peacetime fire scenario(s) (i.e., fully operational water mist system installed in an intact machinery space). The system design requirements (e.g., hardware requirements) will be covered in the ship specification.

2.0 BACKGROUND

2.1 Current U.S. Navy System/Acceptance Testing

In the mid-1990s, halogenated agents/chemicals were linked to stratospheric ozone depletion resulting in the phase-out of the total flooding agent/gas Halon 1301 (the fire protection industry's premier agent for protecting land-based Class B hazards and electronic spaces as well as the machinery spaces on U.S. Navy ships). This event spawned numerous research and development programs to fill the void resulting from the elimination of Halon 1301, one of

which was the U.S. Navy's program established to assess the potential for using water mist for protecting shipboard machinery spaces.

Based on the results of a multi-year program [1, 5, 6], water mist was specified to protect the propulsion machinery spaces on LPD 17 and LHD 8 ships. The system being installed on these two ships is a high pressure, single fluid water mist system designed to operate at 70 bar (1,000 psi). The system consists of modified Spraying Systems nozzles installed in the overhead of each deck level with a nominal nozzle spacing of 2.4 m (8 ft). In this configuration, the system discharges 1.22 Lpm/m^2 (0.03 gpm/ft^2) or 0.4 Lpm/m^3 (0.003 gpm/ft^3). The final acceptance of the LPD 17 water mist system was based on the results of full-scale tests conducted onboard the ex-USS *Shadwell* [1].

During the initial stages of the LPD 17 system development program, it was hoped that water mist could provide the same capabilities as the environmentally unacceptable Halon 1301 system. The inability of water mist to extinguish small obstructed fires was quickly identified but the thermal management capabilities of the system provided additional capabilities not provided by Halon. In short, although the system had difficulty extinguishing small obstructed fires, the ability to quickly extinguish large Class B fires while thermally managing the conditions in the space made the system appealing for the U.S. Navy. The potential for the space to remain occupied during a fire event (combat scenario) was also a significant advantage of water mist.

Since the program was focused primarily on developing a system, the performance requirements of the system were never explicitly stated but are implied in the capabilities section of the validation report [1]. Simply stated, the fires that could not be extinguished by the water mist system had to be approachable and capable of being extinguished using a hand-held portable extinguisher. This is discussed in greater detail later in this report.

During the LPD 17 validation tests [1], the capabilities observed in the smaller test compartments on the ex-*Shadwell* had to be extrapolated (scaled-up) to the machinery spaces on the LPD 17. In order to accurately scale the ex-*Shadwell* results, the effects of oxygen depletion had to be addressed. In compartments with limited ventilation, oxygen depletion effects scale directly with compartment volume. As a result, the extinguishment times were analyzed based on the ratio of fire size to compartment volume. To account for the reduction in oxygen that occurred in the space during the preburn, the fire burn time (preburn time plus extinguishment time) was used in this analysis. The fire burn times were plotted versus the fire size to compartment volume ratio in Fig. 1. A curve fit was then used to predict the fire burn times and the expected extinguishment times (assuming a one minute preburn) for a range of fire sizes for the main (2,150 m^3 (75,800 ft^3)) and auxiliary (1,850 m^3 (66,300 ft^3)) machinery spaces on the LPD 17 and are shown in Fig. 2. The curve fit shown Fig. 1 defines the fire extinguishing capabilities of the Navy system that will serve as the basis for this standard.

2.2 Commercial Standards/Test Protocols

The following information is provided for comparison purposes only. At this time, the U.S. Navy does not explicitly recognize internationally/commercially approved systems for use on Navy ships. With this said, if the commercial standards evolve to the point where the data is

applicable to the requirements defined in this paper, it may be used at a later date to approve systems for U.S. Navy applications/machinery spaces.

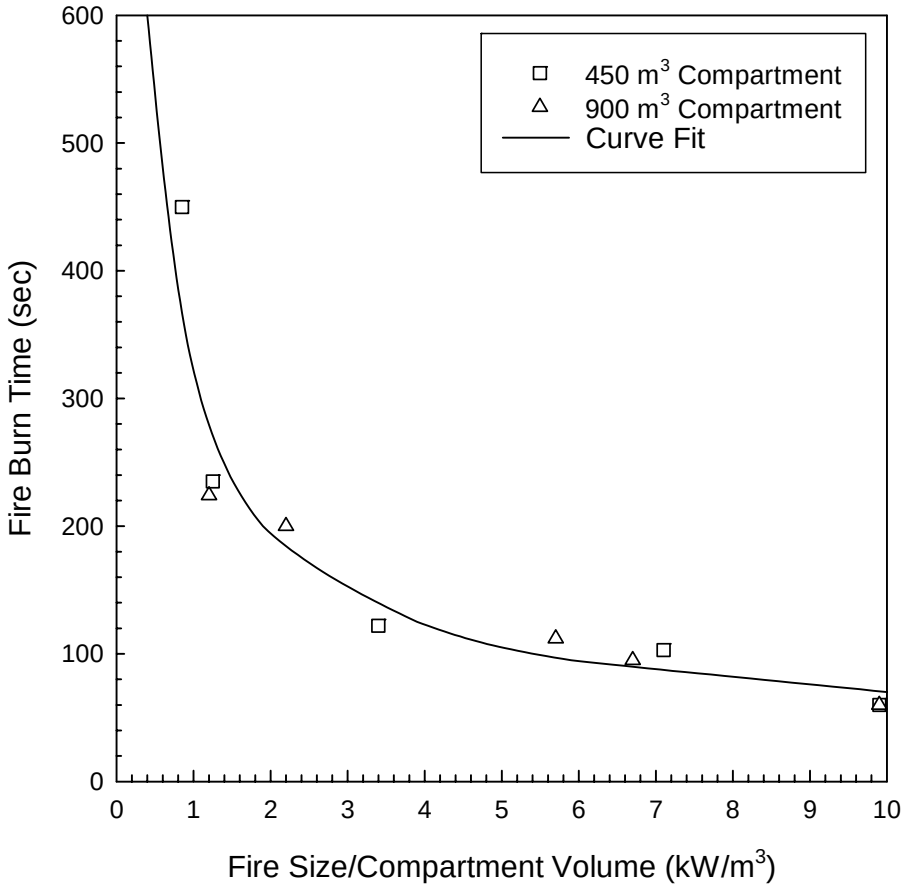

Fig. 1 — LPD 17 system fire extinguishing capabilities (normalized by volume) [1]

There are three primary organizations that have developed water mist test protocols for shipboard applications: International Maritime Organization (IMO); Factory Mutual (FM); and, Underwriters Laboratories, Inc. (UL). IMO develops fire test protocols which are published in the Fire Safety Systems (FSS) Code [7], but does not conduct the tests or issue approvals. Any recognized fire testing laboratory (e.g., FM, SINTEF, SP, UL, or VTT) can conduct the tests and issue an approval. Both FM and UL develop and administer their own test protocols and issue approvals (and listings) based upon successful completion of the standard. The need for approvals from specific laboratories is driven by local regulations and client specifications.

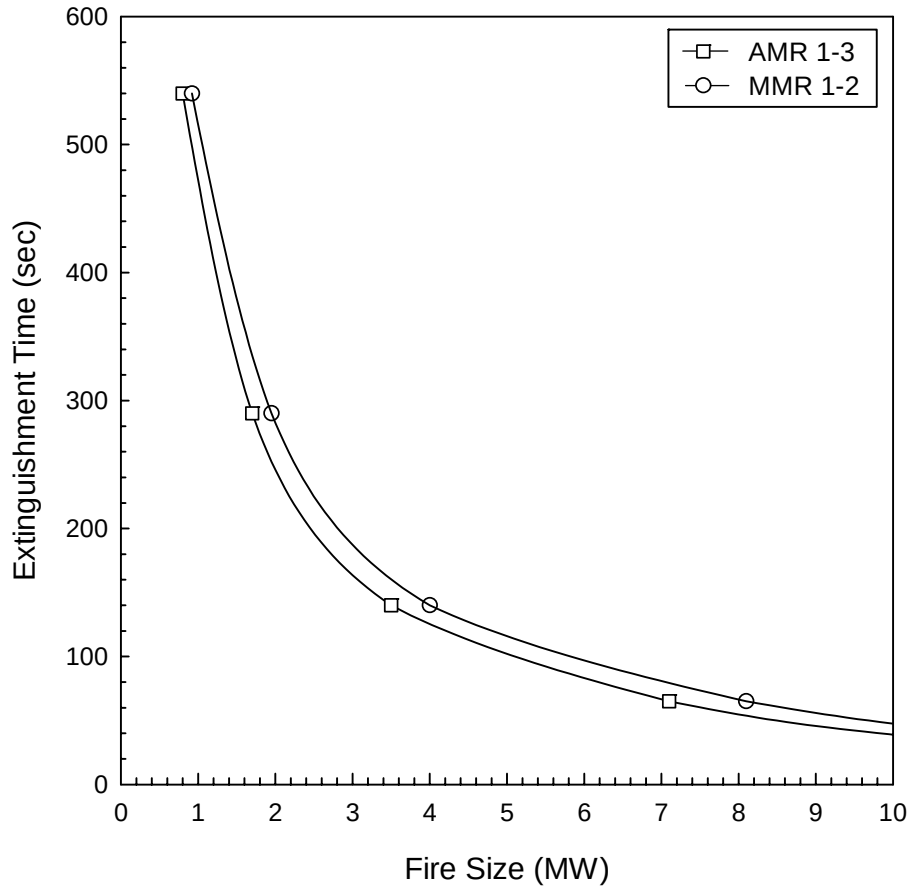

Fig. 2 — LPD 17 extinguishment times [1]

The FSS Code contains a set of IMO test protocols that cover the spectrum of shipboard applications, including both Class A and Class B hazards. MSC/Circ. 668/728 contained in the FSS Code addresses water mist systems intended for application in Category A, machinery spaces (Classes 1, 2, and 3) and has been adopted by FM and UL for approving/listing water mist systems for a range of Class B hazards [8,9]. As a result, the IMO machinery space test protocol has become the commercial standard for approving water mist systems for protecting the spectrum of Class B hazards both on land and at sea.

The test compartment required in MSC 668/728 is dimensioned according to the volumes associated with each class. Air to support combustion is provided through a 2 m x 2 m (6.6 ft x 6.6 ft) ventilation opening.

An example of a Class 1 machinery space test compartment is shown in Fig. 3. An engine mock-up, shown in Fig. 4, that includes simulated exhaust manifolds and grating as well as a simulated bilge area, is located in the center of the compartment and is used for all three machinery space classes.

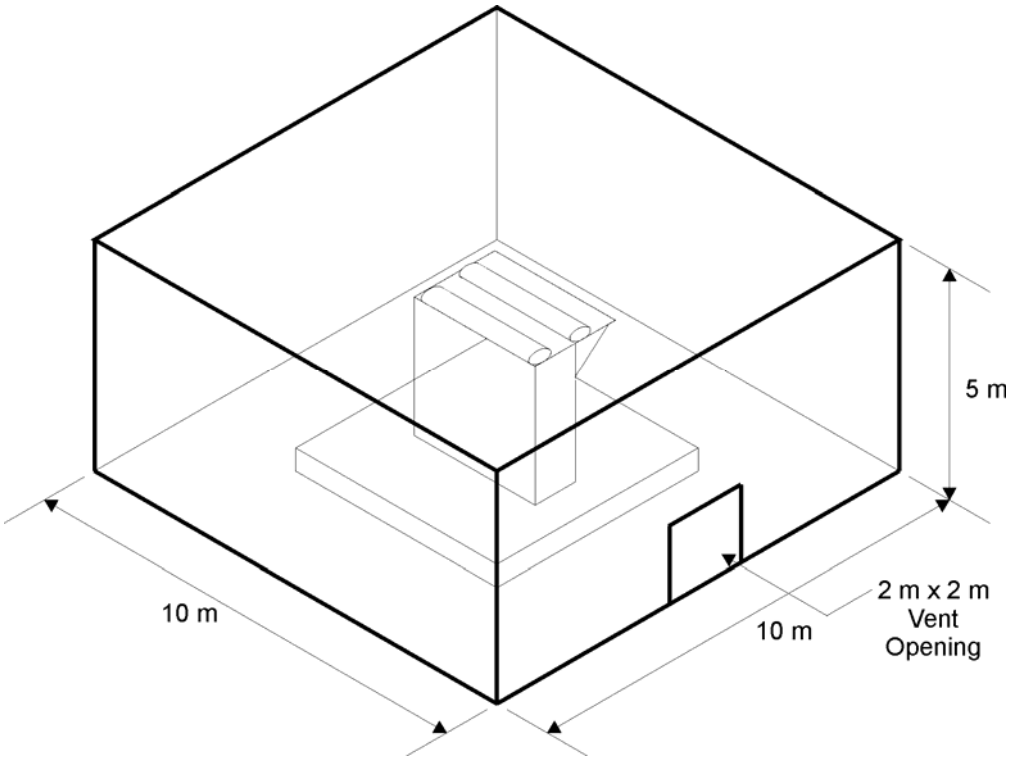

Fig. 3 — IMO Class 1 machinery space configuration

The protocol is currently in a state of flux with major revisions proposed during the 49th meeting of the Fire Protection Sub-Committee of the International Maritime Organization (FP49) in January 2005. If adopted, these revisions will take effect in July 2006. As a result, the two protocols (current and revised) will be discussed separately in the following sections of this report. The basic difference between the two protocols is the size/heat release rates of the test fires.

2.2.1 Current IMO Test Protocol (MSC/Circ. 668)

Thirteen fire scenarios/tests were required in the original test protocol including pool fires, low and high pressure spray fires, and a wood crib fire (see Table 1). The fuels used in these tests include commercial fuel oil or light diesel oil, heptane, and lubrication oil. Most of the fires are obstructed from direct mist interaction with the flame. To successfully complete the protocol, the water mist system must extinguish all fires within 15 minutes of mist system activation and prevent re-ignition from occurring after the end of water discharge. The protocol requires a 30 minute water supply for installed systems. Tests 4, 7, 8, and 13 are intended to evaluate the capabilities of a bilge fire suppression system.

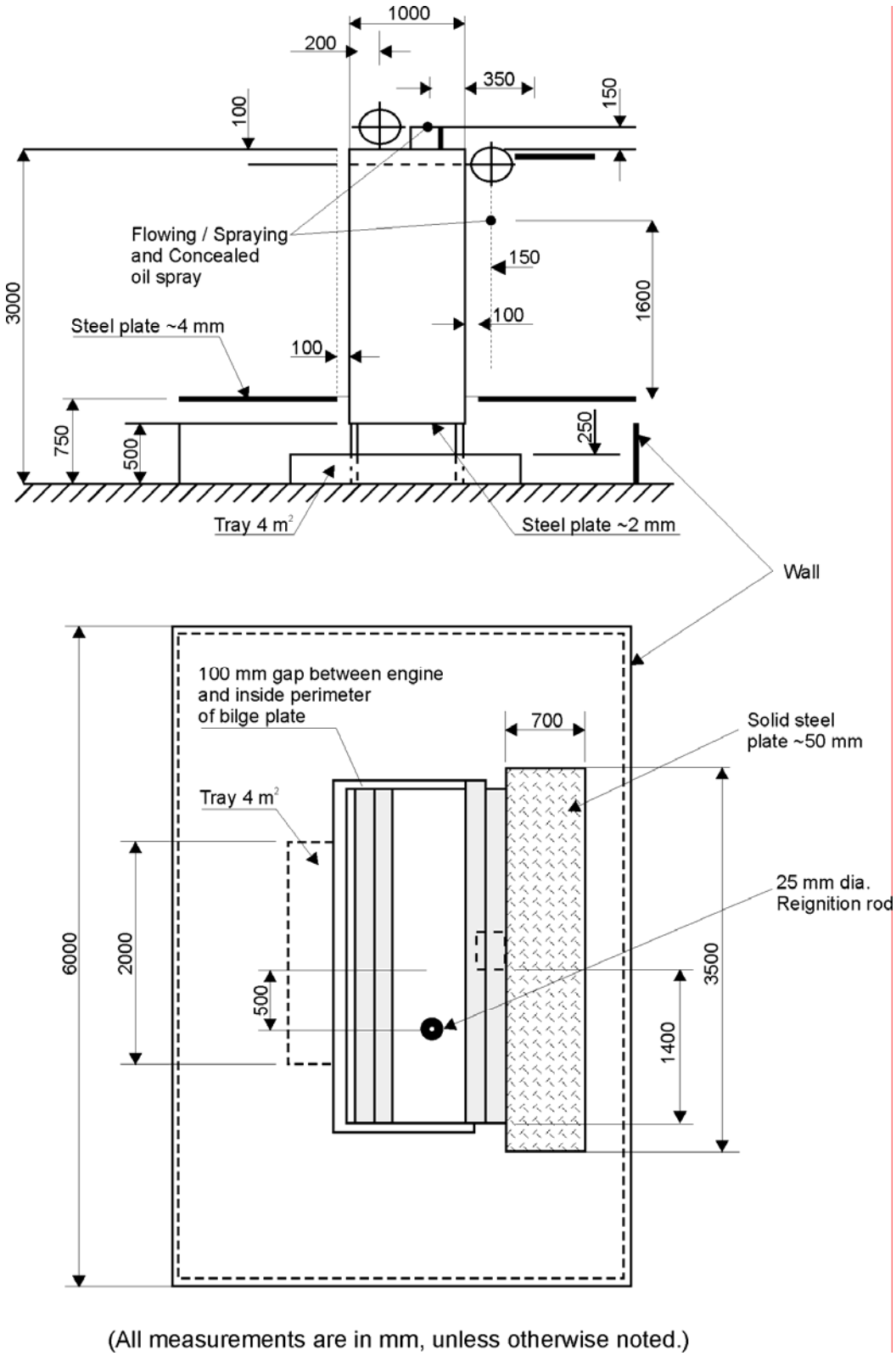

Fig. 4 — IMO diesel engine mockup

Table 1 — IMO Machinery Space Fire Scenarios

Test No.	Fire Scenario	Test Fuel
IMO-1	Low pressure spray on top of simulated engine between agent nozzles (5.8 MW)	Commercial fuel oil or light diesel fuel
IMO-2	Low pressure spray on top of simulated engine with fuel nozzle angled upward at a 45° angle to strike a 12-15 mm diameter rod 1 m away (5.8 MW)	Commercial fuel oil or light diesel fuel
IMO-3	Low pressure, concealed, horizontal spray fire on side of simulated engine with oil spray nozzle positioned 0.1 m in front of the engine (5.8 MW)	Commercial fuel oil or light diesel fuel
IMO-4	Combination of worst spray fire from Tests 1-3 and 4 m^2 pan fire under mockup 3 m^2 pan fire and on top of the simulated engine	Commercial fuel oil or light diesel fuel
IMO-5	High pressure, horizontal spray fire on top of simulated engine (1.8 MW)	Commercial fuel oil or light diesel fuel
IMO-6	Low pressure, low flow, concealed, horizontal spray fire on the side of simulated engine (1.0 MW) and 0.1 m^2 pan fire beside mockup on floor	Commercial fuel oil or light diesel fuel
IMO-7	0.5 m^2 pan fire centered under mock-up	Heptane
IMO-8	0.5 m^2 pan fire centered under mock-up	SAE 10W30 mineral-based lubrication oil
IMO-9	0.8 m^2 on top of bilge plate, centered under exhaust plate	Heptane
IMO-10	Flowing fuel fire (0.25 kg/s) from to of mock-up	Heptane
IMO-11	UL 1626 wood crib in 2 m pool fire with 30 second preburn	Heptane
IMO-12	A steel plate offset to the spray is heated 350°C by a low pressure, low flow spray.	Heptane
IMO-13	4 m^2 pan fire under mock-up	Commercial fuel oil or light diesel fuel

2.2.2 Revised IMO Test Protocol (MSC/Circ. 668R)

During FP 49, the group decided to separate the bilge fire scenarios from those conducted with the overhead nozzles. The group also removed the small spray fire IMO-6 and significantly increased the size of the pan fire in Test 9 (IMO-9). The new fire scenarios are shown in Tables 2 and 3.

In addition to these revisions, the group added an obstructed heptane pool/pan fire test to assess the thermal management capabilities of the system. The size of the fire is based on the volume of the enclosure (2 kW/m^3). The system is not required to extinguish the fire but only needs to reduce the 60 second time-weighted average temperature below 100°C (212°F) no later than 300 seconds after system activation.

2.3 Water Mist System Capabilities

At the time the U.S. Navy specified a water mist system for the machinery spaces on the LPD 17, literally thousands of water mist tests had been conducted by various U.S. Military organizations for this application. The U.S. Army [10], the U.S. Coast Guard [11, 12, 13, 14] and U.S. Navy [1, 5, 6] had each conducted their own separate investigations. The U.S. Navy's investigations were conducted in a closed compartment. Both the U.S. Army and U.S. Coast

Table 2 — Fire Scenarios Proposed by FP49 (Overhead Nozzle Grid)

Test No.	Fire Scenario	Test Fuel
IMO-OH1	Low pressure horizontal spray on top of simulated engine between agent nozzles	Commercial fuel oil or light diesel fuel
IMO-OH2	Low pressure spray in top of simulated engine centered with nozzle angled upward at a 45° angle to strike a 12-15 mm diameter rod 1 m away	Commercial fuel oil or light diesel fuel
IMO-OH3	High pressure horizontal spray on top of the simulated engine	Commercial fuel oil or light diesel fuel
IMO-OH4	Low pressure concealed horizontal spray fire on the side of simulated engine with oil spray nozzle positioned 0.1 m in from the end of the engine and 0.1 m^2 tray positioned on tope of the bilge plate 1.4 m in from the engine end at the edge of the bilge plate closest to the engine	Commercial fuel oil or light diesel fuel
IMO-OH5	Concealed 0.7 m x 3.0 m fire tray on top of bilge plate centered under exhaust plate	Heptane
IMO-OH6	Flowing fire 0.25 kg/s from top of mock-up	Heptane
IMO-OH7	Class A fires wood crib (see note) in 2 m^2 pool fire with 30 s preburn. The test tray should be positioned 0.75 m above the floor as shown in Fig. 1.	Heptane
IMO-OH8	A steel plate (30 cm x 60 cm x 5 cm) offset 20° to the spray is heated to 350°C by the top low pressure spray nozzle positioned horizontally 0.5 m from the front edge of the plate. When the plate reaches 350°C, the system is activated. Following system shutoff, no re-ignition of spray is permitted.	Heptane

Table 3 — Bilge System Fire Scenarios (Segregated During FP 49)

Test No.	Fire Scenario	Test Fuel
IMO-B1	0.5 m^2 central under mock-up	Heptane
IMO-B2	0.5 m^2 central under mock-up	SAE 10W30 mineral-based lubrication oil
IMO-B3	4 m^2 tray under mock-up	Commercial fuel oil or light diesel fuel

Guard investigations were based on the International Maritime Organization's (IMO) test protocol for evaluating alternative arrangements for Halon fire extinguishing systems (MSC Circular 668 [7]). These tests were conducted in well-ventilated compartments (2 m x 2 m (6.6 ft x 6.6 ft) vent openings). The tests conducted to date formed a substantial database for water mist systems installed in machinery spaces having volumes between 100 m^3 to 1000 m^3 (3500 ft^3 to 35,000 ft^3) and varying degrees of ventilation. These test results identified the strengths and limitations of water mist for machinery space applications.

The strengths of water mist are associated with its ability to extinguish a wide range of larger Class B fires while thermally managing the conditions in the space. The reduced temperatures minimize the thermal damage and prevent fire spread to adjacent compartments. The lower temperatures also tend to reduce the airflow through vent openings making these systems somewhat robust with respect to securing all doors to the space, which is a significant advantage over Halon and other gaseous agent systems.

The limitations of water mist are associated with difficulties extinguishing small shielded or obstructed fires. The difficulty with shielded or obstructed fires is associated with high mist fallout rates (due to gravity) which tend to significantly reduce the mist concentration in areas away from the spray pattern of the nozzles. Hence, water mist technologies may never exhibit the same capabilities against small obstructed fires as the gaseous agents.

Although the gaseous behavior of water mist is severely limited, many shielded/obstructed fires can still be extinguished. The extinguishment of these fires is the result of a reduction in oxygen concentration in the space caused by the consumption of oxygen by the fire and a dilution of oxygen with saturated water vapor. In fact, if the fire size is above the critical value dictated by the conditions in the compartment, the fire can still be extinguished without any mist reaching the fire. The principles governing this phenomenon are well understood and a model has been developed to predict this limiting case [15].

The extinguishment time for a fire that requires some degree of oxygen depletion (i.e., obstructed fires) is a function of the fire size, the compartment geometry (volume, surface area, and ventilation rate/conditions) and the amount of mist reaching the fire and/or degree of fire obstruction. For a given water mist system and set of compartment conditions (compartment volume and ventilation), as the fire size is reduced, the extinguishment times tend to exponentially approach a critical fire size below which the fire cannot be extinguished. This trend in the extinguishment capabilities is shown in Fig. 5 for two different size obstruction plates (a plate positioned above the fire to prevent mist from reaching the fire/flame).

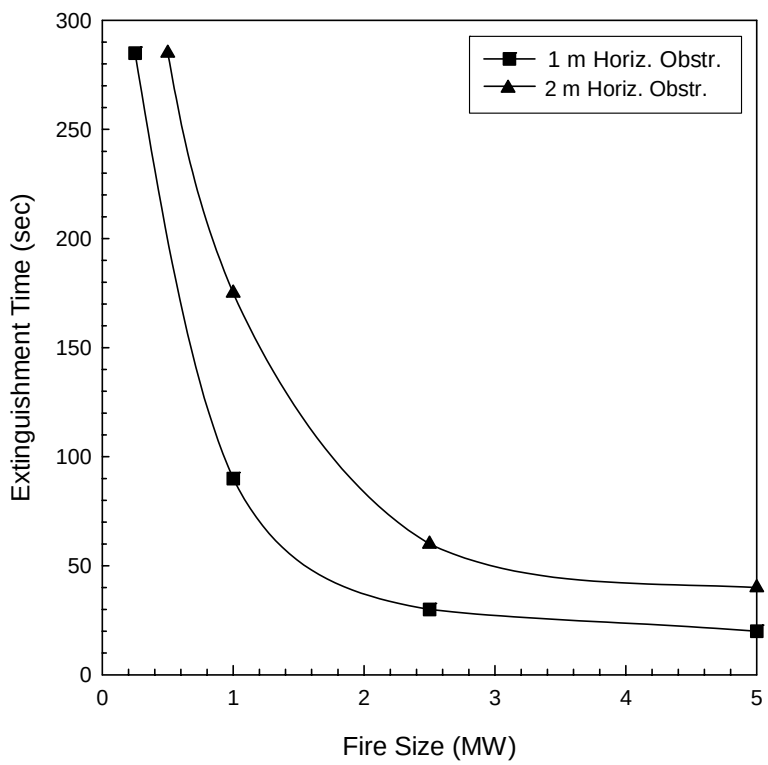

Fig. 5 — Trends in extinguishment times as a function of fire size and fire obstruction

The results of these tests and the predictions made by the model suggest that this critical fire size is primarily a function of the ventilation conditions in the space. If the space was secured prior to mist system activation (as would be done for the gaseous agents), the critical fire size would be driven by the leakage area in the space. For typical leakage areas of 0.1 m^2 (1.1 ft^2), the critical fire size for the space would be less than 100 kW. Unfortunately, the time required to extinguish these small shielded fires is a function of the size (volume) of the space and behaves exponentially as the fire size is reduced to the critical value.

Prior to specifying water mist for the machinery spaces on the LPD 17, these limitations on fire size and the times required to extinguish small obstructed fires were assessed with respect to the fire hazard (typical fire scenarios) and the scenario when the system would actually be discharged. The typical hazard in U.S. Navy machinery spaces was identified as a fast growing Class B fire which would be quickly extinguished by the water mist system. Small fires (fires with heat release rates near the critical value) would be easily approached and extinguished using a portable extinguisher and would not warrant the activation of the total flooding system. In fact, a standard 18 lb PKP extinguisher in the hands of a novice can extinguish well over a 5 MW fire (based on the extinguishers' rating) which is much larger than the critical fire size for even the largest U.S. Navy machinery space [16]. In any case, the space would remain tenable until the fire was extinguished and the likelihood of fire spread to adjacent space would be minimal.

Three other issues were also considered during the selection of water mist for this application. They include toxicity, the effects of the agent on the environment, and a procedural issue associated with the need to abandon/evacuate the space during the discharge of a gaseous agent alternative.

Prior to the selection of mist for this application, the U.S. Navy had banned the use of total flooding CO_2 systems on all surface combatants due to the lethal concentrations required to extinguish a fire. The toxicological effects of new agents that were being developed at the time were still under investigation. Many of these agents (the halocarbons) had already been shown to break down during the extinguishment process and form hydrogen fluoride (HF) producing hazardous conditions and acidic exposures to the equipment in the space. These toxicological effects were seen as a significant liability for selecting a gaseous agent for this application.

Another concern was the effect of the agent on the environment. Although stratospheric ozone depletion was the cause for the elimination of Halon 1301, other issues such as global warming reside in the background. The potential for one of the new gaseous agents to be linked to environmental problems (or physiological effects) in the future was also seen as a significant liability for selecting a gaseous agent for this application.

The final issue was the need to evacuate and secure the space prior to the discharge of a gaseous agent and the inability to re-enter the space for a period of 15 minutes after discharge (15 minute hold time). In a wartime/combat scenario, this 15 minute down time could jeopardize the ship and her crew. Water mist allowed the sailors/DC personnel to remain in the space and/or quickly re-enter the space during the event. The water mist system also has the potential to extinguish fires in spaces where the compartment boundaries have been damaged by the detonation of a weapon (assuming the mist system is still in working condition).

All of these issues led to the selection of water mist for protecting the machinery spaces on the LPD 17 and are summarized in the following list:

- The strengths of water mist are associated with its ability to extinguish a wide range of larger Class B fires while still thermally managing the conditions in the space.
- The small fires that cannot be extinguished are easily approached and extinguished using a standard hand-held portable extinguisher.
- Due to the thermal management capabilities of the water mist system, there is the potential for the sailor to remain in or quickly re-enter the space in a wartime scenario.
- The water mist system has the potential to extinguish fires in a space that has been breached by the effects of a weapon (assuming the system is still operable).
- There were no current or future toxicologic concerns associated with water mist.
- There were no current or future environmental concerns associated with water mist.

3.0 SCOPE

This document provides the test procedures and performance criteria for approving water mist total flooding (deluge) systems for U.S. Navy machinery space applications. At this time, the U.S. Navy is using F76 as the fuel for shipboard combustion engines and boilers (flashpoint 60°C (140°F)). The systems approved using this standard have a built-in factor of safety and are considered acceptable for spaces containing Class B flammable liquids with flashpoints greater than or equal to n-heptane (-4°C (25°F)). Consistent with the IMO test protocol, upon successful completion of the tests in this standard, the system is approved for machinery spaces with volumes up to twice the size (volume) of the test compartment. In this context, the volume of the space is defined as the volume contained within the compartment boundaries.

The performance requirements developed/documented in this paper were intentionally written to allow some degree of flexibility with respect to the test parameters. More specifically, the size of the test compartment and the ventilation conditions are flexible within a given range. This approach was selected since it provides the potential of using test results from different test labs/enclosures, since the size of the test fires is scaled based on the volume of the test enclosure.

These requirements were also developed with the intent that the successful completion of the approval test would ensure an adequate system design (e.g., nozzle spacing and system discharge rate (flow rate per unit volume of protected space)). An alternative approach would be to add additional tests such as spray pattern tests (to ensure complete spray pattern coverage of the space) as well as to require a minimum discharge rate of the system (flow rate per unit volume of protected space).

Although these performance requirements are intended to allow flexibility when testing/approving a system, some requirements/assumptions were needed to aid in the development of the approval test. Most of these assumptions were carry-overs from the Halon 1301 system requirements.

It is assumed that the machinery space to be protected by water mist will be equipped with an AFFF bilge sprinkling system. Additional testing will be required if the AFFF system is removed from the bilge.

Spray fires have been identified as the most likely hazard in U.S. Navy machinery spaces. They are also the most reproducible fires from a fire test stand point. As a result, the fires included in the approval tests are comprised strictly of fuel spray fires (i.e., no pan/pool fires are included in the fire performance assessment).

The installed system is also required to automatically secure the forced/mechanical ventilation in the space upon activation/discharge. If possible, the space shall be evacuated prior to system activation. It is also assumed that the doors to the space will be closed prior to or during discharge. (Note: These doors can be reopened during re-entry into the space to initiate damage control operations.)

Consistent with IMO, NFPA and LPD 17 requirements, [7,17,18] the system must have redundant water supplies (pumps) and an adequate stored water capacity to provide a 30 minute discharge of fresh/potable water. The system shall also be equipped with a sea-water crossover to provide an unlimited discharge duration. The 30 minute discharge of fresh/potable water is required to ensure extinguishment (extinguish, cool surfaces and prevent re-flash) and to allow time for a DC party to confirm the fire is out prior to the switch-over to sea-water. The discharge of sea-water significantly increases the electric shock hazard to personnel in the space [19] as well as the likelihood for nozzles to become clogged with debris from the sea-chest.

4.0 PERFORMANCE REQUIREMENTS

During the development of the water mist system for the LPD 17 [1, 5, 6] the spectrum of available water mist system types and designs were tested with the intent of selecting/developing a system with superior fire protection capabilities. During the testing of these systems, the higher performance (high pressure) systems produced a curve similar to the one selected as the basis for these requirements. The capabilities of the higher performance systems were evaluated over a range of conditions (fire sizes and types, degree of fire obstruction, compartment conditions (e.g., ventilation), nozzle spacings and system operating pressure (40% lower than design to simulate a missing nozzle)). These higher performance systems showed only a limited degradation in capabilities over the range of these variables adding a factor of safety (a robustness to the system) selected for the LPD 17. Other systems could approach these capabilities under some conditions but showed significant degradation (almost unpredictable performance) over the range of potential ship board/machinery space conditions. (This was also observed during the DD(X) evaluations.)

The capabilities of these higher performance systems were selected as the basis for these performance requirements. Simply stated, the fires that can not be extinguished by the water mist system must be small enough to be approached and extinguished using a standard Navy hand-held portable extinguisher. The temperature in the space during the extinguishment of these “smaller” fires must also be maintained to acceptable levels. There may be room to reduce some

of these capabilities/requirements, but it would undermine the logic and the process used to develop and specify the water mist system for the LPD 17.

The following sections define the performance requirements of the system both with respect to extinguishment and thermal management. As a first cut, no system design requirements are placed on the system (e.g., maximum nozzle spacing or minimum discharge rate). It is hoped that the performance/approval tests will ensure the system provides an adequate level of performance. These performance tests are provided as an appendix and are summarized in the following sections of this report.

4.1 Extinguishment Requirements

As stated in the capabilities section of this report, the obstructed fires present the greatest challenge to the water mist system. As a result, obstructed fires will serve as the basis for these requirements.

Since water mist systems are being considered for a range of machinery spaces of various volumes, the performance requirements are expressed in terms of fire size to compartment volume ratio (as discussed in the LPD 17 system validation report) with the caveat that on completion of the standard, the system is approved for machinery spaces with volumes up to twice the size (volume) of the test compartment. The extinguishment time requirements developed based on the LPD 17 test results are shown in Fig. 6.

The extinguishment time requirements shown in Fig. 6 are slightly longer than those observed during the LPD 17 validation tests. The reason for this is two-fold. First, the times were lengthened (by 30 seconds) to account for the shorter pre-burn time used in the test protocol, and second, an additional 15 seconds was added to the time to ensure that all of the tests conducted with the LPD 17 system (hundreds of tests) met these requirements.

The fires used to produce this curve shall be obstructed heptane spray fires located low in the compartment (0.75 m (2.5 ft) above the deck). A 1 m x 2 m (3.3 ft x 6.6 ft) obstruction plate (minimum size) shall be used to shield the fire from direct interaction with the spray patterns of the water mist nozzles. To minimize these interactions, the fire must also be located in the center between four nozzles. This fire location/position and the size of the obstruction will minimize the amount of mist reaching the fire.

At least three different size fires shall be conducted during these tests. The sizes are listed as follows:

	Test #1	$\leq$ 2 kW/m^3
2 kW/m^3 <	Test #2	$\leq$ 4 kW/m^3
4 kW/m^3 <	Test #3	

The extinguishment times of these fires must be less than or equal to those defined by the line on Fig. 6.

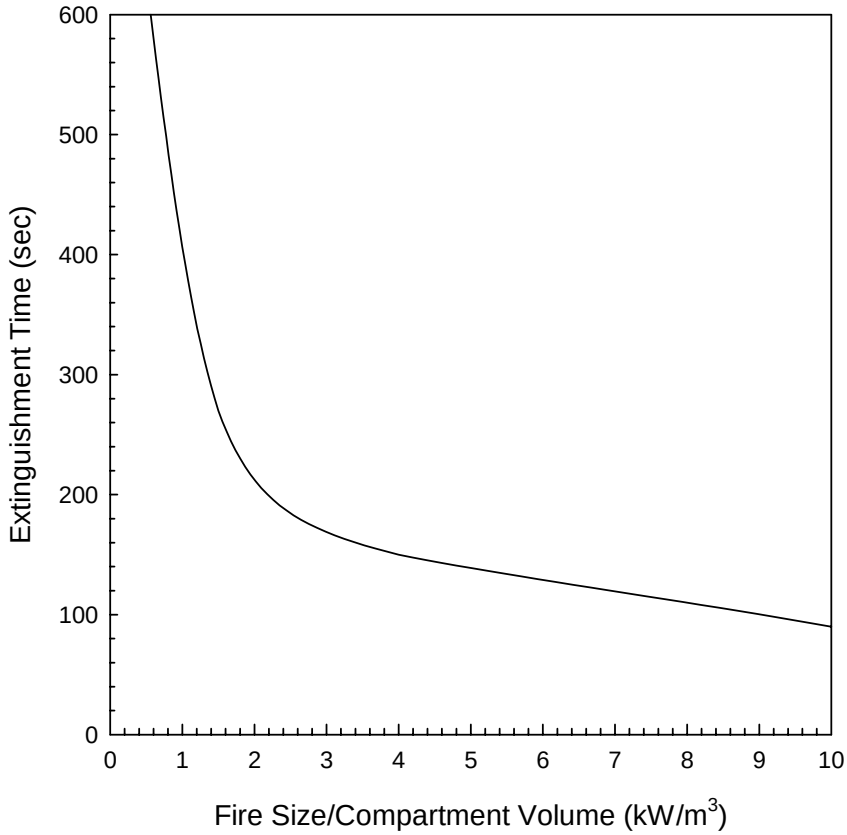

Fig. 6 — Fire extinguishment requirements

The tests shall be conducted in a simulated machinery space with a ceiling height greater than or equal to the desired application (but a minimum of 3 m (10 ft) tall). If the ceiling height of the test enclosure is multiple deck levels tall, uniformly spaced nozzles may be installed in the overhead of each level. If not, a single level of nozzles shall be used. A vent opening with an opening factor ($A\sqrt{H}$ where A=Area of the opening (m^2) and H=Height of the opening (m)) [20] greater than or equal to a standard shipboard watertight door ($A\sqrt{H} \geq 1.67\ m^{5/2}$) [21] shall be installed in one of the bulkheads bounding the space. This opening shall connect the space to the weather and can be located at any elevation on the bulkhead. A detailed description of these extinguishment tests is found in Appendix A.

4.2 Thermal Management Requirements

The thermal management test (described in Appendix A) is intended to ensure that the water mist system discharges an adequate amount of water to maintain the temperatures within the space at tolerable levels and to keep the space well-mixed (fairly uniform temperature) during the extinguishment process. More specifically, to minimize damage to the space and its contents and to maintain tenability to aid in damage control (DC) activities.

The selected temperature criterion is based on potential damage to the respiratory track/system resulting from inhaling air saturated with water vapor. The threshold for respiratory

track damage is approximately 60°C (140°F) [22]. The details on how this temperature is to be measured and at what time into the test is discussed in the following paragraphs.

The size of the test fire is scaled with compartment volume and shall have a heat release rate of at least 2 kW/m^3. This fire size was selected since it typically takes about three to four minutes to extinguish and is large enough to produce untenable conditions throughout the space. The test fire shall consist of a heptane spray fire located under the obstruction plate as described in the extinguishment fire tests. The fire shall be located just above deck level near the center of the space between four water mist nozzles.

Two thermocouple trees shall be installed in the space adjacent to the fire location in the center between four water mist nozzles. Each tree should consist of five thermocouples.

To successfully complete the thermal management test, the average air/gas temperature in the space 60 seconds after mist system activation must be reduced to and maintained below 60°C (140°F) for the duration of the test. In addition, no thermocouple shall exceed 90ºC (194ºF) during the same period of time. This requirement ensures that the space is not only thermally managed but also well mixed. A detailed description of this thermal management test is found in Appendix A.

5.0 SUMMARY

This document defines the test procedures and performance criteria for approving water mist total flooding (deluge) systems for U.S. Navy machinery space applications. The performance requirements were developed based on the capabilities of the LPD 17 system. Simply stated, the system must be capable of quickly extinguishing a wide range of larger Class B fires while thermally managing the conditions in the space. Additionally, fires that cannot be extinguished by the water mist system must be small enough to be approached and extinguished using a standard Navy handheld portable extinguisher. A test/performance standard has been developed to confirm these capabilities and is provided in Appendix A of this report.

The test/performance standard consists of four tests: three extinguishment and one thermal management. The extinguishment tests confirm the fire fighting capabilities of the system while the thermal management test ensures the system can maintain tenability during the fires that require more than a few minutes to extinguish. Systems that successfully complete this standard are approved for machinery spaces with volumes up to twice the size (volume) of the test compartment.

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APPENDIX A

WATER MIST SYSTEM APPROVAL TESTS

1.0 SCOPE

This test method provides the test procedures and performance requirements for approving water mist total flooding systems for U.S. Navy machinery space applications. The systems approved using this standard are considered acceptable for spaces containing Class B flammable liquids with flashpoints greater than or equal to n-heptane (-4°C (25°F)). Upon successful completion of this standard, the system is approved for machinery spaces with volumes up to twice the size (volume) of the test compartment. The volume of the space is defined as the volume contained within the compartment boundaries assuming an empty space. Any deviations from this test method must be approved by NAVSEA 05.

A test plan shall be submitted to NAVSEA 05 for approval prior to the start of testing.

2.0 SETUP

The test setup for qualification testing of total flooding water mist systems shall be as specified in this section. The overall test setup/configuration is shown in Fig. A1.

2.1 Test Compartment

The tests shall be performed in a steel compartment having a specified area greater than 100 m^2 (1075 ft^2), a specified overhead height greater than or equal to the desired application (but greater than 3 m (10 ft)) and natural ventilation through a door opening with a ventilation factor ($A\sqrt{H}$ where A=Area of the vent opening (m^2) and H=Height of the vent opening (m)) greater than 1.67 m$^{5/2}$. This opening can be located on any side (bulkhead) of the compartment and at any elevation.

2.2 Water Mist System

The water mist system shall be installed in accordance with the manufacturer's design and installation manual and shall consist of a uniformly spaced overhead grid of nozzles. The installation manual shall be included as an appendix to the final test report. The nozzle grid shall begin in the corner of the space with the first row of nozzles in each direction the maximum allowable distance away from the boundary and continue across the space with the maximum allowable nozzle spacing.

The test conditions define the maximum height the nozzles can be installed above the deck and/or the maximum vertical spacing between nozzle grids in an actual installation. In either case, the distance between the deck/floor and the lowest level of nozzles and the distance between nozzle grids shall be greater than 3 m (10 ft).

During the test, the system shall be operated at the minimum allowable pressure/flow rate. The system pressure and flow rate shall be continuously measured (1 scan per second) for the duration of the test.

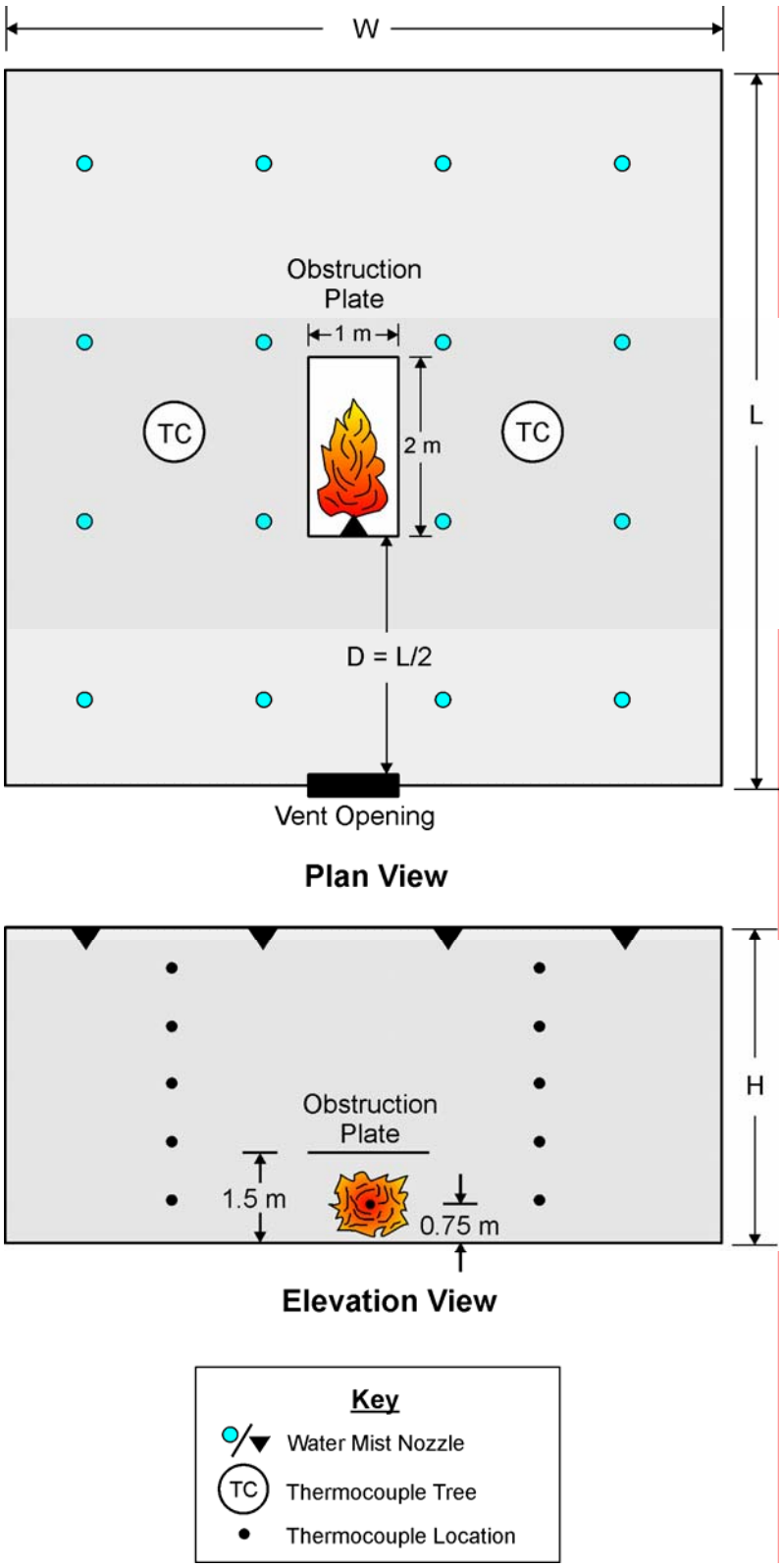

Fig. A1 — Test configuration

2.3 Extinguishment Tests

The extinguishment tests are conducted to verify the extinguishing capabilities of the system over a range of fire sizes. At least three extinguishment tests shall be conducted with each system. The sizes of these fires are scaled as a function of compartment volume. The three sizes are listed as follows:

	Test #1	$\leq$ 2 kW/m^3
2 kW/m^3 <	Test #2	$\leq$ 4 kW/m^3
4 kW/m^3 <	Test #3	

2.3.1 Test Fires

The test fires shall consist of obstructed heptane spray fires located low in the space (0.75 m (2.5 ft) above the deck) as shown in Fig. A2. A 1 m x 2 m (3.3 ft x 6.6 ft) obstruction plate (minimum size) shall be installed 0.75 m (2.5 ft) above the fire to prevent direct interaction between the water mist and the flame. The fires shall be located between four nozzles to represent a worst case location.

The spray fire parameters are given in Table A1. "P" Series nozzles manufactured by BETE Fog Nozzle Inc., Greenfield, MA (or equivalent) shall be used for this application. The heptane spray fires shall be produced using a pressurized source (tank or pump) and a pipe network constructed of 1.2 cm (0.5 in.) stainless steel tubing. Both a manual quarter turn ball valve and a remotely actuated solenoid valve will control the fuel flow. The fuel tank will be pressurized with nitrogen from a regulated cylinder. The fuel spray shall be allowed to preburn for 30 seconds prior to mist system activation and shall be shut off 15 seconds after extinguishment.

Table A1 — Spray Fire Parameters

Fuel Nozzle Model size	Pressure bar (psi)	Flow Rate Lpm (gpm)	Heat Release Rate MW
P48	2.8–5.6 (40–80)	1.51–2.16 (0.40–0.57)	0.8–1.1
P54	2.8–5.6 (40–80)	2.01–2.91 (0.53–0.77)	1.1–1.5
P66	2.8–5.6 (40–80)	2.84–3.97 (0.75–1.05)	1.5–2.1
P80	2.8–5.6 (40–80)	4.09–5.79 (1.08–1.53)	2.1–3.0
P120	2.8–5.6 (40–80)	9.20–12.94 (2.43–3.42)	4.9–6.8

For larger fires or fires not covered in this table, multiple numbers of the same nozzle/model shall be used.

2.3.2 Instrumentation

At least three thermocouples shall be installed in the plume of each fire to verify if and when the fire was extinguished during the test. These thermocouples shall be installed directly in front of the fuel spray nozzle at 0.5 m (1.6 ft) spacings away from the nozzle. These instruments shall be scanned at a rate of one measurement per second.

Closed-circuit remote monitoring with visual and IR cameras shall be utilized during the tests and placed to provide an unobstructed close-up view of the fire during test.

The heptane spray fire shall be instrumented to measure the fuel flow rate (and subsequently heat release rate of the fire) during the test. At a minimum, nozzle pressure shall be measured during the test although it is recommended that a flow meter be installed in the system as well.

An instrumentation plan shall be included in the test plan submitted to NAVSEA 05 for approval prior to testing.

2.3.3 Procedure

Safety procedures prescribed by the test facility shall be observed at all times. For qualification tests, a small heptane pan fire (telltale) shall be used to ignite the spray fire at the start of the test. The telltale shall be ignited and placed adjacent to the fuel spray nozzle prior to the test. The test is initiated by activating the fuel delivery system, which should instantly produce the spray fire of the desired size. The water mist system shall be activated 30 seconds after the initiation of the heptane spray fire (fuel flow). The test shall continue until the fire is extinguished or until the water mist system has been activated for a period of 10 minutes (whichever happens first). The fuel spray shall be secured 15 seconds after extinguishment.

2.3.4 Pass/Fail Criterion

The candidate water mist system shall be considered to have passed the fire extinguishment tests if the extinguishment times are less than or equal to those defined by the line on Fig. A2.

2.4 Thermal Management Test

Only one thermal management test is required for each system. The thermal management test is conducted to ensure that the water mist system can minimize the damage to the space and can maintain tenability within the space during the extinguishment of the fire. The size of the test fire is scaled as a function of the compartment volume and shall have a heat release rate of at least 2 kW/m^3.

2.4.1 Test Fires

The test shall consist of an obstructed heptane spray fire located low in the space (0.75 m (2.5 ft) above the deck) as shown in Fig. A2. A 1 m x 2 m (3.3 ft x 6.6 ft) obstruction plate (minimum size) shall be installed 0.75 m (2.5 ft) above the fire to prevent direct interaction between the water mist and the flame. The fire shall be located between four nozzles to represent a worst case location.

The spray fire parameters are the same as those described in the extinguishment tests and are given in Table A1.

For larger fires or fires not covered in this table, multiple numbers of the same nozzle/model shall be used.

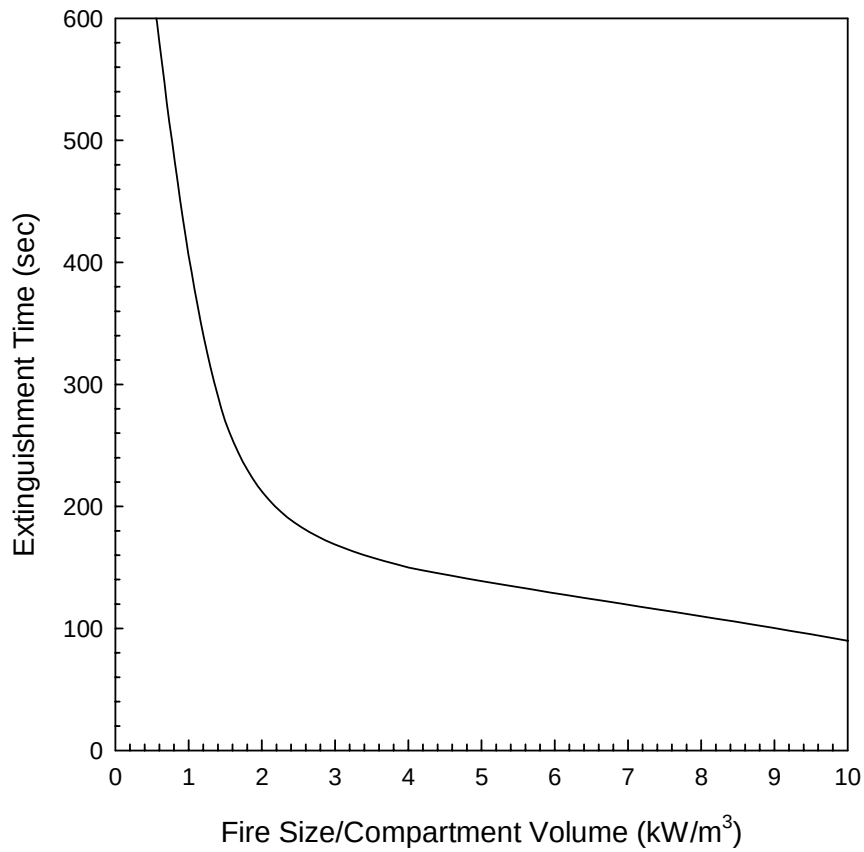

Fig. A2 — Extinguishment test pass/fail criterion

2.4.2 Instrumentation

At least three thermocouples shall be installed in the plume of each test fire to verify if and when the fire was extinguished during the test. These thermocouples shall be installed directly in front of the fuel spray nozzle at 0.5 m (1.6 ft) spacings away from the nozzle. These instruments shall be scanned at a rate of one measurement per second.

Closed-circuit remote monitoring with visual and IR cameras shall be utilized during the tests and placed to provide an unobstructed close-up view of the fire during test.

The heptane spray fire shall be instrumented to measure the fuel flow rate (and subsequently heat release rate of the fire) during the test. At a minimum, nozzle pressure shall be measured during the test although it is recommended that a flow meter be installed in the system as well.

Two thermocouple trees shall be installed in the space adjacent to the fire location and positioned in the center between four water mist nozzles as shown in Fig. A1. Each tree shall consist of five thermocouples of diameter not exceeding 0.5 mm (0.20 in.), positioned at the following heights: 1) 0.5 m (1.6 ft) below the overhead, 2) 0.5 m (1.6 ft) above deck level, 3) at mid-height of the test compartment, 4) between the uppermost thermocouple and the

thermocouple at mid-height, and 5) between the lowest thermocouple and the thermocouple at mid-height.

The temperatures from these trees shall be measured at least once a second for the duration of the test.

An instrumentation plan shall be included in the test plan submitted to NAVSEA 05 for approval prior to testing.

2.4.3 Procedure

Safety procedures prescribed by the test facility shall be observed at all times. For qualification tests, a small heptane pan fire (telltale) shall be used to ignite the spray fire at the start of the test. The telltale shall be ignited and placed adjacent to the fuel spray nozzle prior to the start of the test. The test is initiated by activating the fuel delivery system instantly, which should produce the spray fire of the desired size. The water mist system shall be activated 30 seconds after the initiation of the heptane spray fire (fuel flow). The test shall continue until the fire is extinguished or until the water mist system has been activated for a period of 10 minutes (whichever happens first). The fuel spray shall be secured 15 seconds after extinguishment.

2.4.4 Pass/Fail Criterion

The candidate water mist system shall be considered to have passed the thermal management test if the average temperature of all the air/gas thermocouples installed in the space (on the two thermal couple trees adjacent to the fire) 60 seconds after mist system activation is reduced to and maintained below 60°C (140°F) for the duration of the test. In addition, no thermocouple shall exceed 90°C (194ºF) during the same period of time.

3.0 OBSERVATIONS AND FINAL REPORT

3.1 Observations

During the test the following items shall be recorded:

1. When the test was started
2. The time when the extinguishing system was activated
3. The time when the fire was extinguished, if it was
4. The time when the extinguishing system was shut off
5. The time of re-ignition, if any
6. The time when the fuel flow for the spray fire was shut off
7. The time when the test was secured
8. Data from all test instrumentation

- Spray fire system pressure and flow rate
- Water mist system pressure and flow rate
- Compartment temperatures
- Fire temperatures

3.2 Final Report

The test report should include the following information:

1. Name and address of the test laboratory
2. Date and identification number of the test report
3. Name and address of client
4. Purpose of the test
5. Name and address of manufacturer or supplier of the product
6. Name or other identification marks of the product
7. Description of the tested product
    - Drawings
    - Descriptions
    - Assembly instructions
    - Specification of included materials
    - Detailed drawing of test setup
8. Date of supply of the product
9. Date of test
10. Test description
11. Drawing of each test configuration
12. Measured nozzle characteristics
13. Identification of the test equipment and used instrumentation
14. Conclusions
15. Deviations from the test method, if any
16. Test results including observations during and after the test
17. Date and signature
18. Appendix – Design and installation manual of approved system